Neuropsychologia, Vol. 19, No. 2, pp. 161–169, 1981.
Printed in Great Britain
0028-3932/81/020161-09$02.00/0

© 1981 Pergamon Press Ltd.

SELECTIVE MUSICAL PROCESSING DEFICITS IN BRAIN DAMAGED POPULATIONS

BARBARA E. SHAPIRO, MURRAY GROSSMAN and HOWARD GARDNER*

Psychology Service, Boston Veterans Administration Medical Center
Department of Neurology, Boston University School of Medicine, and Harvard Project Zero

(*Received* 17 *July* 1980)

Abstract—Unilaterally brain damaged patients were asked to judge the correctness of familiar melody lines. Sixty per cent of these items contained either pitch, rhythm, tempo, or phrasing errors. With respect to the detection of pitch errors, right anterior patients performed significantly worse than all other groups; right central patients exhibited an intermediate level of difficulty; *all* left brain damaged (aphasic) groups were nearly flawless. For the detection of rhythm and phrasing errors, control, left anterior and left posterior groups did well while right anterior, right central and left central groups did poorly. Results suggest that the anterior right hemisphere may be critical in the processing of pitch components of music; the right hemisphere in general may be important in maintaining the internal auditory representation of musical material, essential for detecting violations in performance.

INTRODUCTION

THE ISSUES of how one processes musical material, and the extent to which each hemisphere is involved, have been the subjects of inquiry and debate for at least a century (for review see [1–3]. While many investigators have focused on the processing of specific musical components, such as pitch, rhythm, and tempo in both normal and brain damaged populations [4, 5], few have examined the extent to which the processing of these components breaks down separately, or in unison, in various brain damaged populations. Such investigations are useful in determining how musical capacity is represented in the brain and whether musical processing skills break down in an across-the-board fashion or more selectively for specific components according to the locus of lesion.

Much evidence concerning the processing of musical material has been gathered to date from studies of normal individuals and clinical studies of brain damaged populations. The majority of evidence has implicated the right hemisphere [6–9], although this is not systematically true for all components of music [4], nor for all individuals [10]. Results are further complicated by the use of musicians vs. non-musicians in similar tasks. For example, in a dichotic listening task, BEVER and CHIARELLO [11] found a left-ear preference for melody recognition in non-musicians, but a right-ear preference in musicians. Finally, most studies have required the subject to make judgments on unfamiliar highly artificial stimuli presented in isolation, a process that may bear little resemblance to the way one customarily processes music. Furthermore, the task often involves a short-term memory component, that of comparing two unfamiliar tonal sequences, which may confound the actual musical judgment.

---

*Mailing address: Psychology Service: 14th floor-116-B, Boston Veterans Administration Medical Center, 150 South Huntington Avenue, Boston, MA 02130, U.S.A.

In the present investigation, subjects without appreciable musical training who had sustained either left anterior, left central, left posterior, right anterior or right central unilateral brain lesions were asked to judge whether highly familiar melody lines were played correctly or not. In this context, the melody line was either left intact, or one of four components—pitch, rhythm, phrasing or tempo—was altered to produce an incorrect rendition. It was hypothesized that normal control and left brain damaged groups in general would perform better overall than right brain damaged patients, although subgroups within the left and right brain damage classifications would differ in their performance. Furthermore, patient groups would be differentially impaired in the processing of specific musical components depending upon site of lesion. Specifically, in the light of previous research [4–9], right brain damaged groups would have the most trouble detecting items with pitch errors, while left brain damaged groups would have trouble detecting items containing rhythm errors. Moreover, because of their oft-noted sequencing deficits [12–14], patients with left hemisphere damage would have trouble with items containing phrasing errors, in which part of the melody line was actually deleted. It was also hypothesized that if errors were in some way accentuated within the melody line, (e.g. pitch errors played out of key vs. in key; the inclusion of five vs. three rhythm errors), they would be more easily detected by groups which ordinarily encountered difficulty processing these musical elements.

METHODS

Subjects

Subjects included twenty-eight right-handed patients with localized cerebral insult to either the right or left hemisphere, and five normal control subjects. All subjects were high school or college educated native English speakers between 35 and 65 years of age who had not pursued professional musical training in the past twenty years. Patients were classified into five experimental groups on the basis of radiological findings (either CT scan or brain scan); supporting neuropsychological assessment including performance on the Boston Diagnostic Aphasia Examination [15]; and clinical findings including field cuts, hemiplegia, and hemisensory loss. Subject groups were comprised of sixteen patients with left hemisphere damage, including five Broca's aphasics with syntactic deficits but good lexical comprehension as a result of left anterior insult; six mixed aphasics with left central lesions (these patients were non-fluent with fair to good comprehension and evidence of both pre- and post-Rolandic insult); and five fluent aphasics with poor comprehension secondary to left posterior (temporo-parietal) insult. Twelve non-aphasic patients with right hemispheric insult were examined, including seven with lesions primarily restricted to the anterior region of the right hemisphere and five with right central lesions with primarily parietal, but also pre-Rolandic insult. Five normal control subjects matched in age, socio-economic status, and educational level to the brain damaged patients were also tested.

Materials

Stimulus items consisted of forty-six, eight-bar pieces of familiar songs played on the piano and without lyric accompaniment (e.g. "O! Susanna", "Silent Night"). Stimulus items were selected by a panel of five judges who independently scored the familiarity of a series of eight-bar melody lines. Only those items that were determined to be highly familiar by all five judges were included in the present study. Twenty-eight of these items, or approximately sixty per cent of them, contained only one of four specific types of musical errors, including pitch errors (eight items), rhythm errors (eight items), phrasing errors (eight items) and tempo errors (four items). Moreover, there were two variation within each type of musical error as follows.

For pitch errors, four wrong notes were substituted for four correct notes at specified points in the course of the item, of which two incorrect notes were two tones above the correct note and two notes were two tones below the correct note. Half of these items with pitch errors contained incorrect pitches that were in key and the remainder exhibited errors which were out of key. For rhythm errors, a short-value/long-value (or long-value/short-value) pair of notes was reversed in order, (e.g. 𝅗𝅥 ♪ ► ♪ 𝅗𝅥), while the correct sequence of pitches was maintained. Half of these items with rhythm errors contained three rhythm reversals, while the remainder contained five rhythm reversals. Both the pitch and rhythm items consisted of the initial eight bars of the melody lines. For the phrasing errors, a phrase of music four bars in length was deleted from the middle of the initial twelve bars of a melody line. Half of these deletions were at phrase markings, while the remainder did not coincide with phrase markings. Finally, four pieces were played with tempo errors, in which the initial eight bars of the melody line were played too quickly in half of the items, and too slowly in the remainder. The remaining eighteen items contained no errors. All items were presented to the subject on a cassette tape.

Procedure

Subjects were seated in a quiet testing room with the experimenter and a portable cassette tape recorder directly in front of them. A brief training session was administered prior to the actual testing session in order to familiarize the subject with each type of stimulus item and the required response, and to determine a comfortable listening level for the subject. Subjects were told that they would hear some familiar segments of music, some of which would be played correctly and some incorrectly. Each item was played twice, and the subject was asked to judge whether the segment he heard sounded correct or not.

In the training session, eight items (which constituted a representative selection of the kinds of items used in the actual test) were played in a random order. In this session, generally lasting no more than ten minutes, items were played twice but repeated upon request, and feedback was given on the correctness of the subject's responses. However, at no time were the types of errors specifically named or explained by the experimenter. Only those subjects who clearly understood the task and were able to indicate either verbally or through gesture whether the piece sounded correct or not proceeded with the test session. Two patients, not included in the initial description of subjects, failed to understand the task. During the actual testing session, the forty six items were presented to each subject in the same random order. No feedback was given during the testing session and no items were played more than twice. Subjects were encouraged to guess if they were unsure of their answer and to report any songs they did not recognize.

RESULTS

Results will be presented in the following manner. Differences between control, aphasic, and right brain damaged groups as a whole will be examined, followed by a more detailed analysis of differences between control and each of the aphasic and right brain damaged subgroups. For each of these analyses, group differences in overall performance will precede a more specific analysis of group differences for each item type. Finally, performance profiles of each group across all item types will be presented.

Differences in overall performance between aphasic patients as a whole, right brain damaged patients as a whole, and normal control subjects were examined in a two-factor Group (3) × Item (5) repeated measures analysis of variance on number of correct responses. Analysis revealed significant main effects for Group ($F=10.12$; $df=2{,}30$; $P<0.001$) and Item Type ($F=33.27$; $df=4{,}120$; $P<0.001$), and a significant Group × Item Type interaction ($F=6.35$; $df=8{,}120$; $P=0.032$). A Duncan's Multiple Range Test of Means revealed that normal controls and aphasics performed significantly better, overall, than the right brain damaged groups ($P<0.05$).

Separate analyses of variance for each item type revealed significant group differences for pitch ($f=7.35$; $df=2{,}30$; $P=0.003$), rhythm ($F=17.24$; $df=2.30$; $P<0.001$), and phrasing ($F=4.93$; $df=2{,}30$; $P=0.015$) items only. For each of these, a Duncan's Multiple Range Test showed that both aphasic and control groups performed significantly better than the right brain damaged groups ($P<0.05$). For control and tempo items, no significant differences were found between groups.

Aphasic and right brain damaged groups were then separated, respectively, into left anterior, left central, and left posterior aphasic patients and anterior and central right brain damaged groups and again compared with the control group in overall performance. A two-factor, Group (6) × Item Type (5) repeated measures analysis of variance was performed, again revealing significant main effects for Group ($F=5.17$; $df=5,27$; $P=0.002$) and Item Type ($F=18.34$; $df=4,108$; $P<0.001$) and a significant Group × Item Type interaction ($F=2.19$; $df=20,108$; $P=0.006$). A Duncan's Multiple Range Test of group means showed that, overall, the control, left anterior, and left posterior groups performed the best with 88, 87 and 77% items correct, respectively, while right anteriors and right centrals were the worst, with 60 and 64% items correct, respectively. Left central patients were intermediate in performance, with 71% of the items correct.

Separate analyses of variance were then performed on each item type, and for each subject group. The analyses for each item type revealed significant group differences for pitch ($F=4.21$; $df=5,27$; $P=0.006$), rhythm ($F=8.67$; $df=5,27$; $P<0.001$) and phrasing ($F=4.27$; $df=5,27$; $P=0.006$) items only. When each of these item types was examined separately, using a Duncan's Multiple Range Test, characteristic group differences emerged as outlined in Fig. 1. For the pitch items, right anterior patients performed significantly worse than all other groups ($P<0.05$). No other significant group differences were found, although there was a tendency for the right central group to perform worse than the aphasic and control groups. For the rhythm items, right anterior and right central patients performed significantly worse than control, left anterior and left posterior groups ($P<0.05$). The left central aphasics were intermediate in performance: they performed at significantly worse levels than the control and the other two aphasic subgroups, yet significantly better than the right anteriors ($P<0.05$). For the phrasing items, right anterior, right central and left central groups performed significantly worse than control, left posterior and left anterior groups ($P<0.05$).*

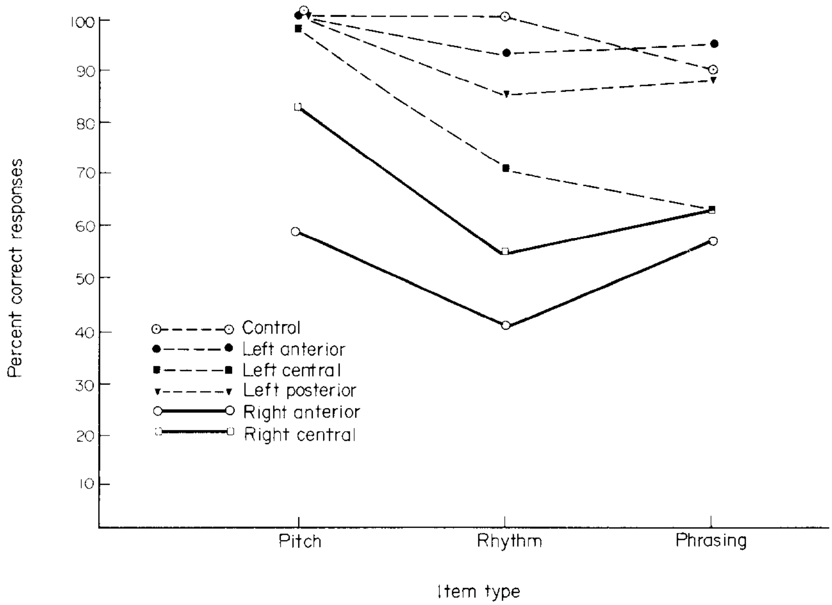

FIG. 1. Per cent items correct on pitch, rhythm and phrasing items for all subject groups.

---

*As this article went to press, we had the opportunity to test a patient with a right posterior (temporo-parieto-occipital) lesion secondary to a cerebrovascular accident. His performance was flawless on pitch, rhythm, and phrasing items, thus revealing none of the deficits of the other right brain damaged groups.

To determine performance profiles within each group, Duncan's Multiple Range Tests were performed on each of the various item types within groups. For all groups, pitch items were the easiest and tempo items the most difficult, except for the right anteriors, for whom control items proved the easiest and rhythm items the most difficult. The following trends within groups were observed. Control, left anterior and left posterior groups exhibited a rather flat profile, doing well on all items types, with the exception of the tempo items. Right anteriors, in contrast, did poorly on all item types, with the exception of their good performance on control items. Left central and right central patients had a more varied profile: they tended to do poorly on rhythm, phrasing and tempo items and relatively better on pitch and control items (See Table 1).

Table 1. Per cent items correct in each subject group for each item type.

Subject group	Item type Control	Pitch	Rhythm	Phrasing	Tempo
Control	89	100	100	90	60
Left anterior	78	100	93	95	70
Left posterior	85	100	85	88	25
Left central	89	98	71	63	38
Right central	77	83	55	63	40
Right anterior	82	59	41	57	61

None of the variations within item types (i.e. pitch errors: in-key vs. out-of-key; rhythm errors: three vs. five; tempo errors: fast vs. slow; phrasing errors: consistent with vs. violating phrase markings) proved to be significant, nor were there any significant Group × Item Type Variation interactions. Thus, there was no evidence to suggest that any of the groups were either aided or hindered by the blatancy of the violation within an item type.

Subject reports of song recognition revealed that aphasic and right brain damaged groups reported non-recognition of songs in 4 and 6% of the songs, respectively, while this was reported by normal controls in less than 1% of the songs. Moreover, for all groups the percentage of songs not recognized was fairly evenly distributed among all item types with the exception of tempo items, which were much less frequently recognized. These results must be interpreted with caution, however, as there was no accurate way of assuring that patients reported all of the songs that they did not recognize.

DISCUSSION

The present results reveal differences in overall performance between aphasic, right brain damaged, and control groups as well as differential breakdown in the processing of various musical components within certain organic subgroups. Normal controls and aphasic patients were significantly better at detecting all types of musical errors, with the exception of tempo errors,* than the right brain damaged patients. Moreover, within the aphasic group, left anterior and left posterior aphasics showed the best performance overall. The depressed performance of the right brain damaged groups was attributable primarily to the right anteriors.

---

*All groups, including the control subjects, did poorly on the tempo items, which contributed to most of the significant within-group differences. Though it is possible that many of the subjects were unable to perceive alterations in tempo, it is more likely that these alterations were simply not perceived as errors during the testing session. Thus, subjects frequently remarked that the songs sounded right, though they were played either too quickly or too slowly.

While these results suggest that musical material may be "of a whole", that left anterior and left posterior aphasics detect all types of musical errors while right anteriors do poorly at everything, this characterization alone cannot explain the performance of either the left central aphasics or the right central group: the left central aphasics were nearly flawless in their detection of pitch errors, in sharp contrast to their significantly impaired performance in the detection of either rhythm or phrasing errors. This trend was also observed within the right central patients, although results did not reach significance, and their performance on pitch items was by no means perfect (See Fig. 1).

It is reasonable, therefore, to suggest that at least some components of music—pitch, rhythm, and phrasing—may indeed be processed separately and show differential sensitivity to various types of brain damage. For example, the right anterior patients performed significantly worse than all other groups in detecting pitch errors, although the performance of the right central group was also somewhat impaired. The diminished performance of both right brain damaged groups on the pitch items, especially the right anteriors, in contrast to the nearly perfect performance of *all* aphasic groups for these items, suggests that the ability to detect changes in pitch may depend on an intact right hemisphere, and more specifically, the anterior region of the right hemisphere. This point is dramatically underscored by the case of the left central aphasics, for whom the ability to detect pitch errors in a musical judgment task was uniquely spared.

Although a right anterior (left brain damage) advantage was found for the detection of pitch errors, no left hemisphere (right brain damage) advantage was found for the detection of rhythm errors. Such an advantage had been expected, given previous findings of right ear (left hemisphere) superiority for the processing of rhythmic components of music in a dichotic listening paradigm [4, 16]. In fact, in the present study just the opposite effect was found: right brain damaged groups did the worst, although the left central aphasic patients also did poorly. A similar pattern of breakdown was observed for the phrasing items. The processing of both these types of errors may require the ability to detect changes across a sequence of tones. Two possible explanations can be offered for the poor performance of both right brain damaged and left central aphasic patients in detecting rhythm and phrasing errors. First, the ability to detect these errors in familiar musical pieces may require the combined mediation of both hemispheres: while the central portion of the left hemisphere may mediate the sequential aspects of auditory stimuli in general, there is evidence to suggest that the right hemisphere is involved in processing sequences across pitches [14].

On the other hand, the central portions of the left hemisphere alone may be crucial in the processing of rhythmic and phrasing elements of music, and thus the poor performance of the left central aphasic patients, while the right hemisphere groups may have done poorly for an entirely different reason. There is some evidence to suggest that patients with right hemisphere damage have a poor "internal auditory representation" of musical material in general. We have recently observed the performance of a non-aphasic patient with extensive musical training who suffered a small silent left hemisphere lesion followed by a large right hemisphere stroke, leaving him with a complex auditory processing disorder including elements of word-deafness, receptive amusia, and auditory sound agnosia. This patient was unable to answer from memory simple questions concerning sound relationships in musical material with which he claimed to be familiar. Such a deficit has not been noted in other bilateral word-deaf patients with larger left hemisphere strokes. Our observations suggest that the right hemisphere may be important in maintaining an internal auditory representation, or auditory image, of musical material. In the present study it is postulated that patients with right brain lesions had a disturbed internal auditory representation of the musical pieces they heard, and were unable to compare what they heard with an accurate representation of the song. This would account for the impaired performance of these groups in judging all types of musical errors including pitch, rhythm, and phrasing errors.

It is unlikely that the right brain damage deficit can be attributed to an input-perceptual problem; were this the case, performance would have been equally poor on control and error items (i.e. pitch, rhythm, phrasing and tempo), which was simply not the case. For example, while the right anteriors performed at about chance level on pitch, rhythm and phrasing items, they were still 82% correct on control items. This suggests that they had some idea, albeit vague, of what the song should sound like, and made correct judgments more often when the stimulus item they heard sounded the way it would sound if it were played correctly. It was expected that patients' performance would improve the more blatantly the stimulus item deviated from the way it should have sounded. Unfortunately, neither the left nor right hemisphere groups benefited in performance from the variations introduced within item types. Perhaps these variations were not robust enough to make a critical difference, especially for the right hemisphere patients; for the left hemisphere patients, there may have been a ceiling effect.

While this vague representation notion may account for all of the right brain damage group deficits in making musical judgments, this does not, however, exclude the previously raised possibility that the processing of "pitch" components depends primarily on right anterior function. Only the right anterior group was significantly impaired compared to all other groups in detecting pitch errors. The right hemisphere has been implicated in other modalities that involve pitch modulation. For example, monotonic speech, or lack of pitch variation, has been well documented in patients with right hemisphere damage [17]. More recently, ROSS and MESULAM [18] have reported specifically on two patients with right anterior damage who were unable to modulate their speech in the expression of emotions. Clearly, the relationship between the processing and modulation of pitch elements needs further exploration across several domains including music, emotions, language and environmental sounds.

Alternative explanations for the present results receive little support. First, there is no evidence to suggest that the right anterior patients, who performed the worst overall, had more extensive lesions than either the right central or even the aphasic groups. Second, the performance of the right anterior patients cannot be attributed to a positive response set bias, a tendency to accept all songs as being played correctly. Had such a bias been present, right anterior patients should have done better on the control items and worse on the error items than they actually did. Another conceivable explanation is that right anterior patients were simply unable to recognize songs with errors in them, and thus had no systematic way of judging their correctness. Subjective reports of song recognition do not bear out this hypothesis. The overall report of non-recognition of songs was low and did not differ between patient groups (4–6%). Moreover, the percentage of songs not recognized was equally distributed among control items, which contained no errors, and all other item types, with the exception of tempo items, which were less frequently recognized.

In summary, the performance of aphasic and right brain damaged groups suggests that musical processing skills do not break down in an across-the-board fashion. This point is most clearly manifested in the performance of the left central aphasics, for whom the ability to detect pitch changes was spared in the face of impaired performance on rhythm and phrasing items. Furthermore, while there is evidence to suggest that both hemispheres are involved in the processing of rhythmic and phrasing components of familiar musical material, the anterior region of the right hemisphere has been strongly implicated in the processing of pitch elements. Performance on the present task also suggests that the right hemisphere may be essential in maintaining an internal auditory representation of musical material. It is noteworthy that in the present study subjects were asked to make judgments about basic elements of music embedded in a familiar musical context. Furthermore, no short-term memory component was necessary to perform this task. Thus, although results did not coincide entirely with predictions made from past investigations, the present results may be more reflective of actual musical processing skills in both normal and brain damaged populations than those reported to date.

Acknowledgements—This research was supported by the National Institute for Neurological Diseases, Communication Disorders, and Stroke (NS 11408, NS 06209, and NS 15972), the Veterans Administration, and Harvard Project Zero. We would like to thank Dr. Michael P. Alexander, Dr. James Liljestrand and the staff of the Braintree Rehabilitation Hospital, Dr. Anna Pomfret and the staff of the New England Rehabilitation Hospital and Wendy Wapner of the Boston Veterans Administration Medical Center for their help in carrying out various phases of this investigation. Portions of this paper were presented at the annual meeting of the International Neuropsychological Society, San Francisco, January, 1980.

REFERENCES

1. Gates, A. and Bradshaw, J. The role of the cerebral hemispheres in music. *Brain Lang.* **4,** 403–431, 1977.
2. Critchley, M. and Henson, R. A. *Music and the Brain: Studies in the Neurology of Music.* Charles C. Thomas, Springfield, 1977.
3. Wertheim, N. The amusias. In *Handbook of Clinical Neurology*, Vol. 4. P. J. Vinken and G. W. Bruyn (Editors), pp. 195–206. North Holland, Amsterdam, 1969.
4. Gordon, H. W. Left hemisphere dominance for rhythmic elements in dichotically-presented melodies. *Cortex* **14,** 58–70, 1978.
5. Milner, B. Laterality effects in audition. In *Interhemispheric Relations and Cerebral Dominance.* V. B. Mountcastle (Editor), pp. 107–195. Johns Hopkins Press, Baltimore, 1962.
6. Zatorre, R. J. Recognition of dichotic melodies by musicians and non-musicians. *Neuropsychologia* **17,** 607–617, 1979.
7. Kimura, D. Left-right differences in the perception of melodies. *Q. J. exp. Psychol.* **16,** 355–358, 1964.
8. Shankweiler, D. Effects of temporal lobe damage on perception of dichotically presented melodies. *J. comp. physiol. Psychol.* **62,** 115–119, 1966.
9. Gordon, H. W. and Bogen, J. E. Hemispheric lateralization of singing after intracarotid sodium amylobarbitone. *J. Neurol. Neurosurg. Psychiat.* **37,** 727–738, 1974.
10. Yund, E. W. and Efron, R. Dichotic competition of simultaneous tone bursts of different frequency—II. Suppression and ear dominance functions. *Neuropsychologia* **13,** 137–150, 1975.
11. Bever, T. G. and Chiarello, R. J. Cerebral dominance in musicians and non-musicians. *Science* **185,** 137–139, 1974.
12. Efron, R. Temporal perception, aphasia, and *déjà vu. Brain* **86,** 403–424, 1963.
13. Albert, M. L. Auditory sequencing and left cerebral dominance for language. *Neuropsychologia* **10,** 245–248, 1972.
14. Swisher, L. and Hirsh, I. J. Brain damage and the ordering of two temporally successive stimuli. *Neuropsychologia* **10,** 137–152, 1972.
15. Goodglass, H. and Kaplan, E. *The Assessment of Aphasia and Related Disorders.* Lea and Febiger, Philadelphia, 1972.
16. Robinson, G. M. and Solomon, D. J. Rhythm is processed by the speech hemisphere. *J. exp. Psychol.* **102,** 508–511, 1974.
17. Monrad-Krohn, G. H. Dysprosody or altered "melody of language". *Brain* **70,** 405–423, 1947.
18. Ross, E. D. and Mesulam, M. Dominant language functions of the right hemisphere? Prosody and emotional gesturing. *Arch. Neurol.* **36,** 144–148, 1979.

Résumé :

On a demandé à des malades avec lésions cérébrales unilatérales de juger si des lignes mélodiques familières étaient ou non correctes. 60% de ces items contenaient des erreurs soit de la hauteur, soit du rythme, soit du tempo soit du phrasé. Dans la détection des erreurs de hauteur, les malades avec lésion antérieure droite avaient des performances significativement inférieures à celles de tous les autres groupes; les malades avec lésion centrale droite avaient des performances intermédiaires; tous les groupes de lésion gauche (aphasiques) avaient des performances presque parfaites. Dans la détection des erreurs de rythme et de phrasé, le groupe de contrôle et les groupes avec lésions gauches antérieures et postérieures avaient de bonnes performances tandis que les groupes avec lésions droites antérieures et centrales et le groupe avec lésion centrale gauche avaient des performances déficitaires. Ces résultats suggèrent que l'hémisphère droit dans sa partie antérieure peut représenter la localisation critique pour le traitement des composantes de hauteur de la musique; l'hémisphère droit en général peut être important pour maintenir la représentation auditive interne du matériel musical.

Zusammenfassung:

Von einseitig hirngeschädigten Patienten wurde ein Urteil darüber verlangt, ob bekannte Melodien richtig dargeboten waren. 60 % dieser Aufgaben enthielten entweder Tonhöhe-, Rhythmus-, oder Betonungsfehler. Patienten mit rechtsseitiger Schädigung in vorderen Hirnabschnitten entdeckten Tonhöhenunterschiede signifikant schlechter als alle anderen Gruppen. Patienten mit rechtsseitig zentraler Hirnschädigung hatten ein mittleres Fehlerniveau. Alle linksseitig geschädigten (aphasischen) Gruppen hatten fast keine Schwierigkeiten. Für die Feststellung von Rhythmus und Phrasierungsfehlern, waren die Leistungen von Kontrollpersonen,von Patienten mit linksseitig vorderer und linksseitig rückwärtiger Hirnschädigung gut, während Patienten mit rechtsseitig vorderer, rechtsseitig zentraler und linksseitig zentraler Hirnschädigung schlecht waren. Die Ergebnisse legen die Annahme nahe, daß der vordere Anteil der rechten Hemisphäre bei der Verarbeitung der Tonhöhenkomponenten von musikalischen Stimuli kritisch sein könnte. Die rechte Hemisphäre könnte im ganzen eine Bedeutung dafür haben, die interne akustische Repräsentation für musikalisches Material aufrecht zu erhalten, die notwendig ist, um Fehler in dieser Modalität zu bemerken.